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Kobayashi et al.

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(54) **OPTICAL FIBER ORIENTATION DETECTION METHOD AND APPARATUS**

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(73) Assignee: **FUJITSU LIMITED**, Kawasaki (JP)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

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G01B 11/26	(2006.01)
G01D 5/30	(2006.01)
G01B 11/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G01B 11/26*** (2013.01); ***G01B 11/002*** (2013.01); ***G01D 5/268*** (2013.01); ***G01D 5/30*** (2013.01)

(58) **Field of Classification Search**

CPC G01D 5/26; G01D 5/268

USPC 250/227.11, 227.14, 227.24, 227.28, 250/227.29, 227.31, 227.32; 385/9, 39, 88, 385/89, 97

See application file for complete search history.

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U.S. PATENT DOCUMENTS

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Primary Examiner — Kevin Pyo

(74) *Attorney, Agent, or Firm* — Staas & Halsey LLP

(57) **ABSTRACT**

A method is provided for detecting an orientation of an optical fiber including a flat surface as a part of a surface of the maintaining member. The method includes directing collimated light to the optical fiber through the flat surface of the maintaining member, receiving reflected light of the collimated light by using an optical sensor device, generating a brightness distribution image according to an output signal from the optical sensor device, identifying a reference point on a brightness distribution line appearing on the generated brightness distribution image, according to a position of the brightness distribution line in relation to a target orientation for the optical fiber, the brightness distribution line detectable on the brightness distribution image in correspondence to the reflected light received by the optical sensor device, and detecting the orientation of the optical fiber according to a coordinate of the reference point on the brightness distribution image.

7 Claims, 18 Drawing Sheets

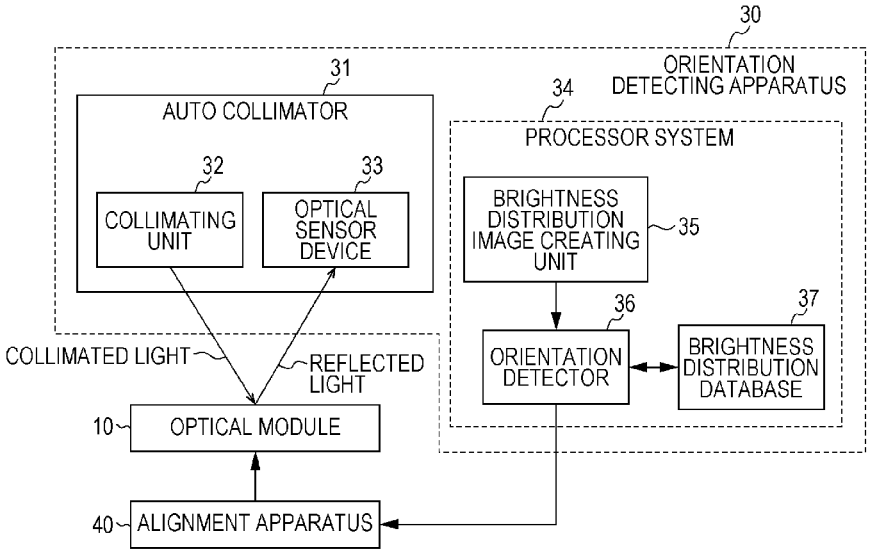


FIG. 1
RELATED ART

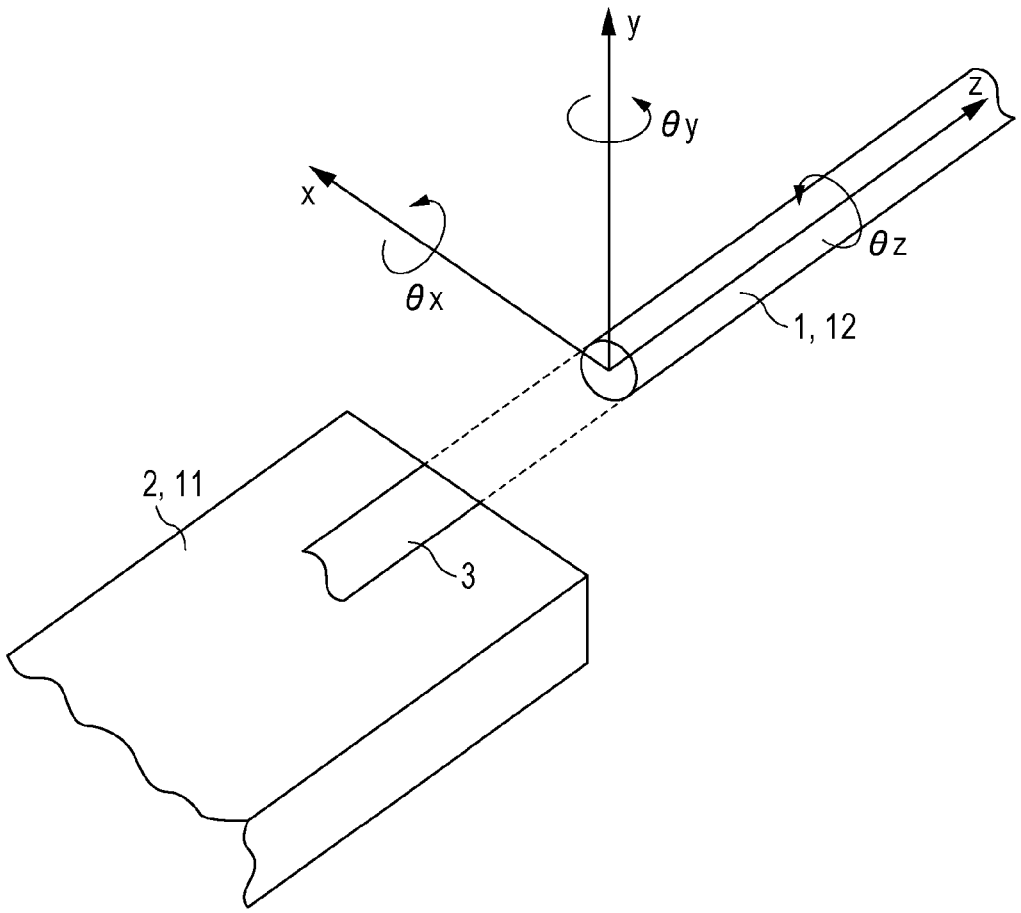


FIG. 2A
RELATED ART

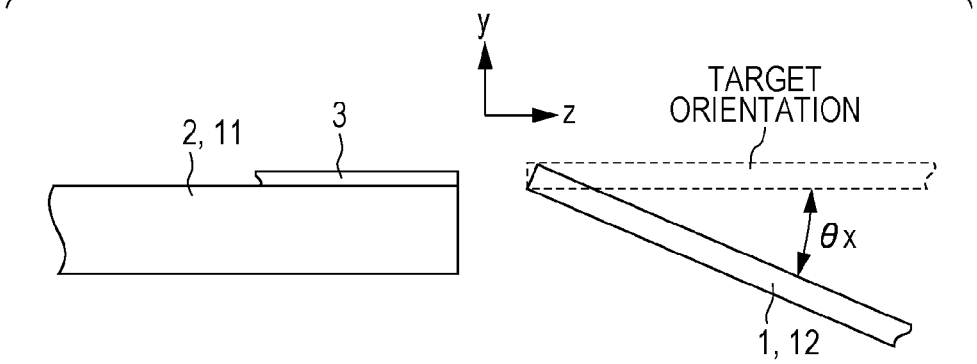


FIG. 2B
RELATED ART

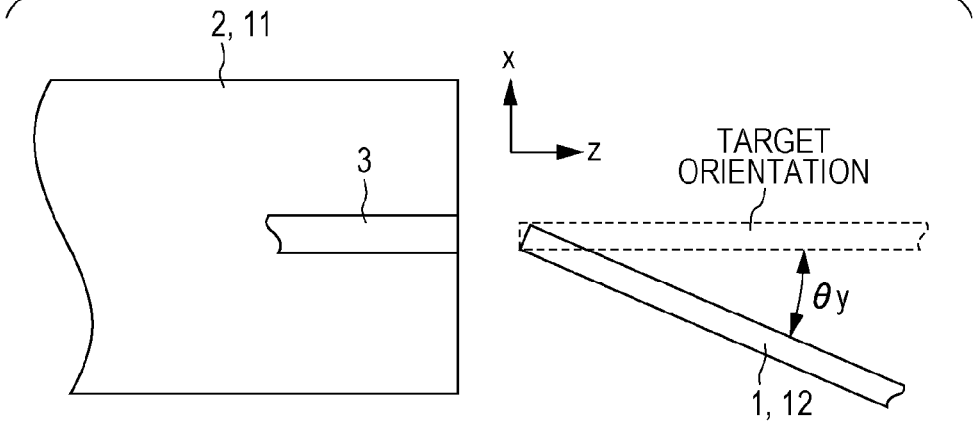


FIG. 2C
RELATED ART

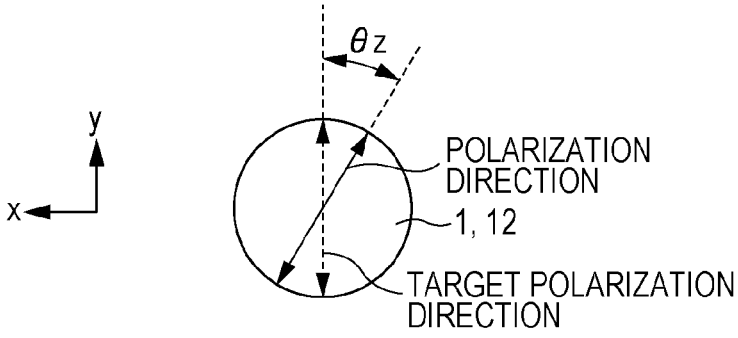


FIG. 3A

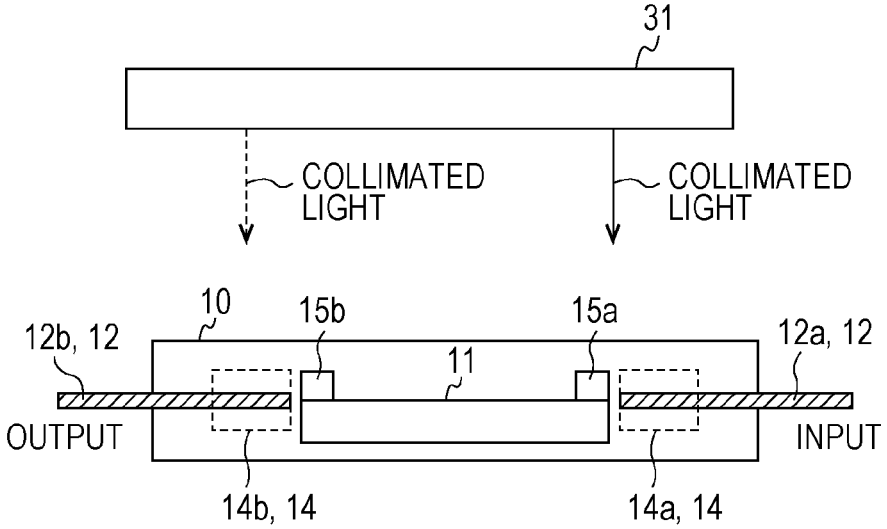

31
COLLIMATED LIGHT
COLLIMATED LIGHT
10
15b
15a
12b, 12
11
12a, 12
OUTPUT
INPUT
14b, 14
14a, 14

FIG. 3B

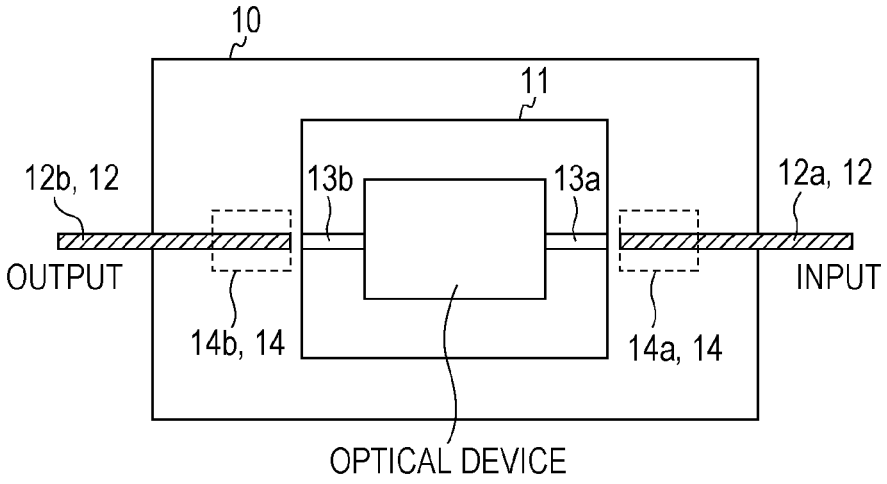

10
11
12b, 12
13b
13a
12a, 12
OUTPUT
INPUT
14b, 14
14a, 14
OPTICAL DEVICE

FIG. 4A

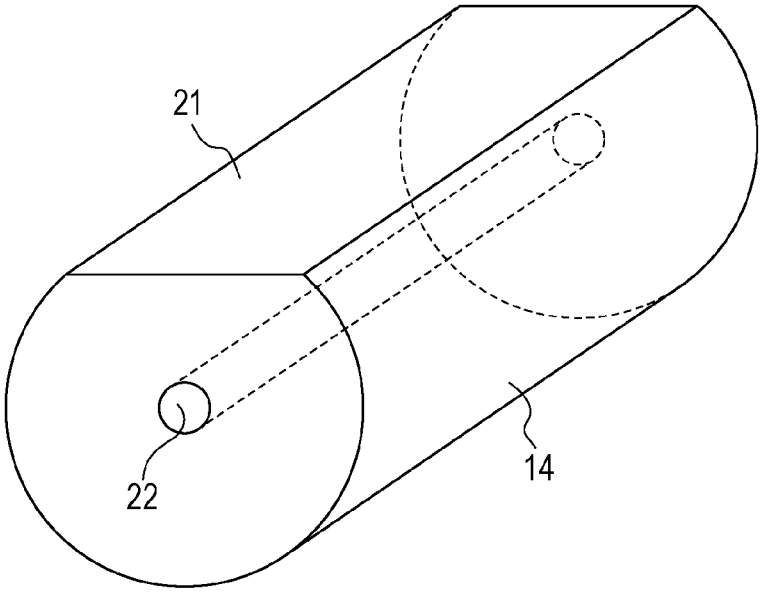


FIG. 4B

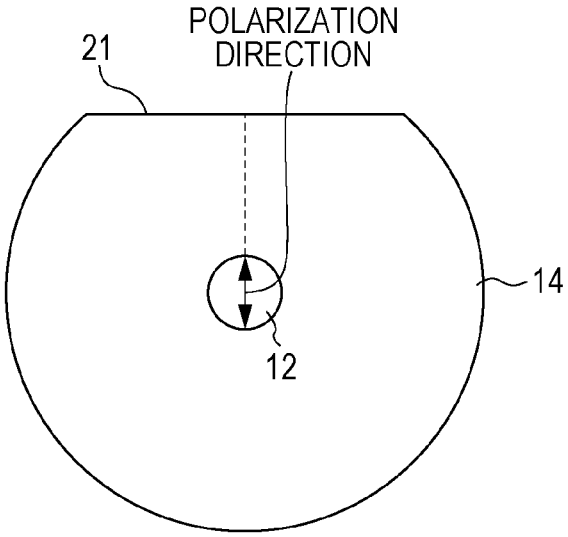


FIG. 5

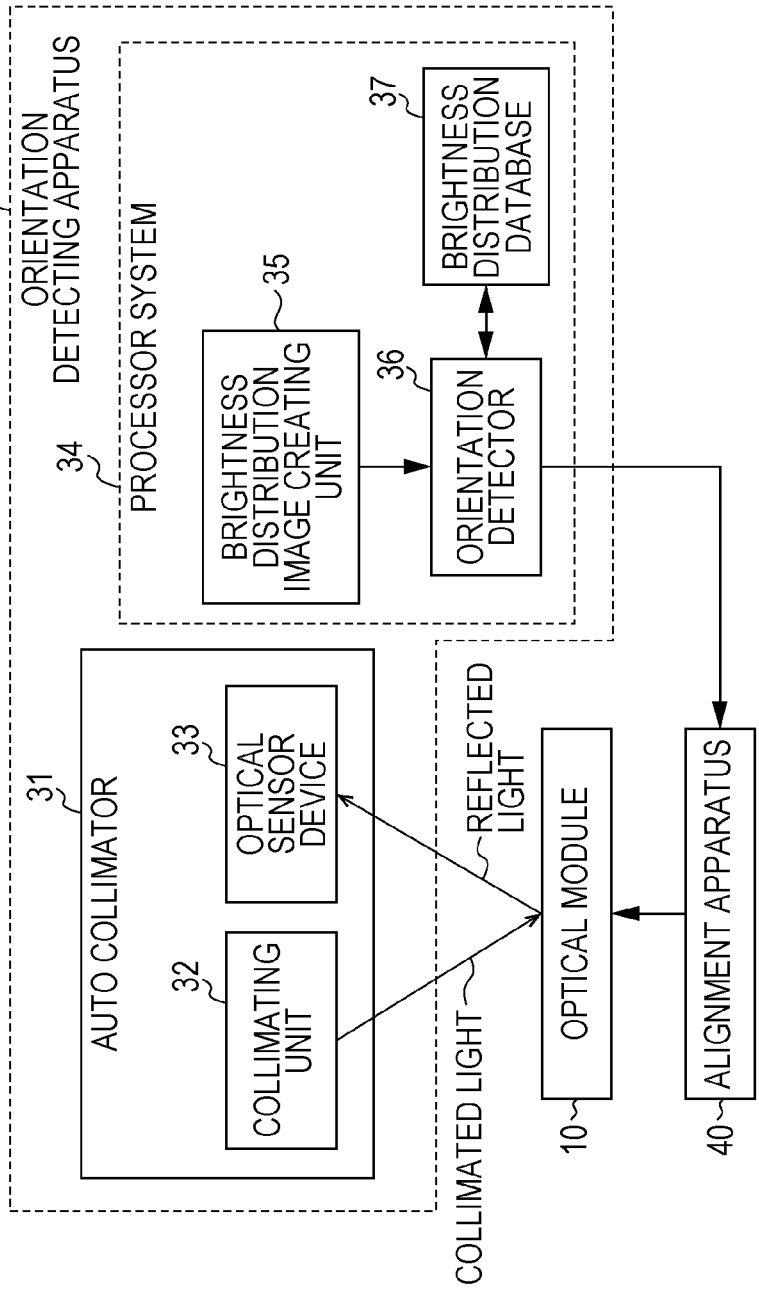

30
ORIENTATION DETECTING APPARATUS
34
PROCESSOR SYSTEM
37
BRIGHTNESS DISTRIBUTION DATABASE
35
BRIGHTNESS DISTRIBUTION IMAGE CREATING UNIT
36
ORIENTATION DETECTOR
31
AUTO COLLIMATOR
33
OPTICAL SENSOR DEVICE
32
COLLIMATING UNIT
REFLECTED LIGHT
COLLIMATED LIGHT
OPTICAL MODULE
10
ALIGNMENT APPARATUS
40

FIG. 6A

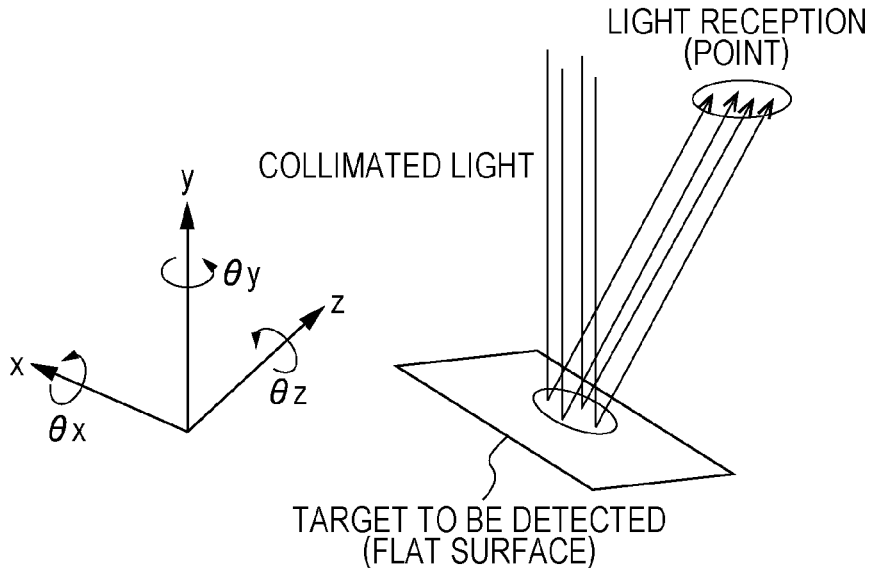

LIGHT RECEPTION
(POINT)
COLLIMATED LIGHT
y
θy
z
x
θz
θx
TARGET TO BE DETECTED
(FLAT SURFACE)

FIG. 6B

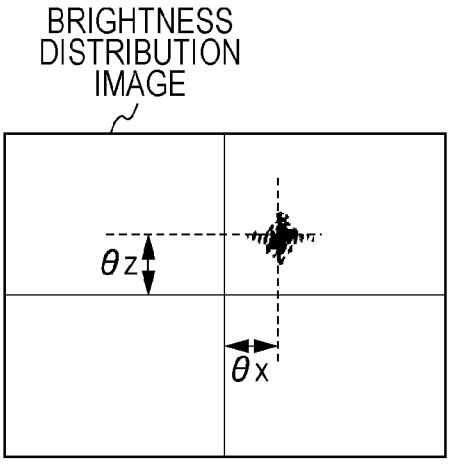

BRIGHTNESS
DISTRIBUTION
IMAGE
θz
θx

FIG. 7

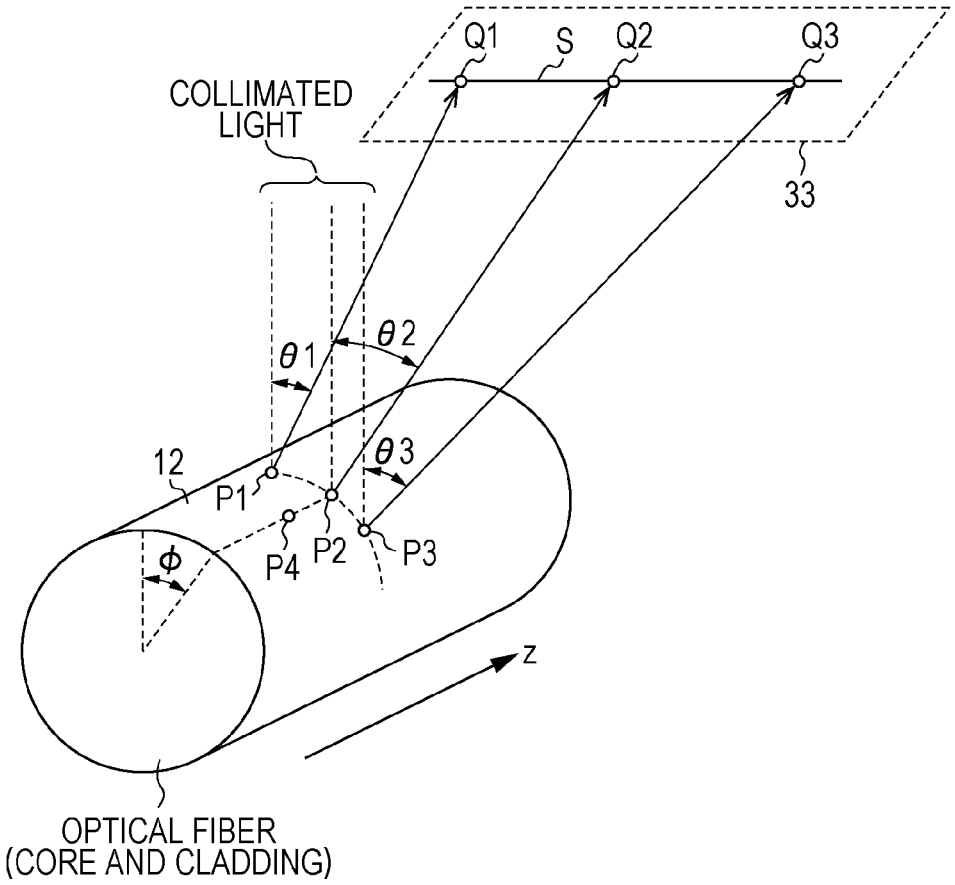

Q1
S
Q2
Q3
COLLIMATED LIGHT
33
θ1
θ2
θ3
12
P1
P2
P3
P4
ϕ
z
OPTICAL FIBER
(CORE AND CLADDING)

FIG. 8

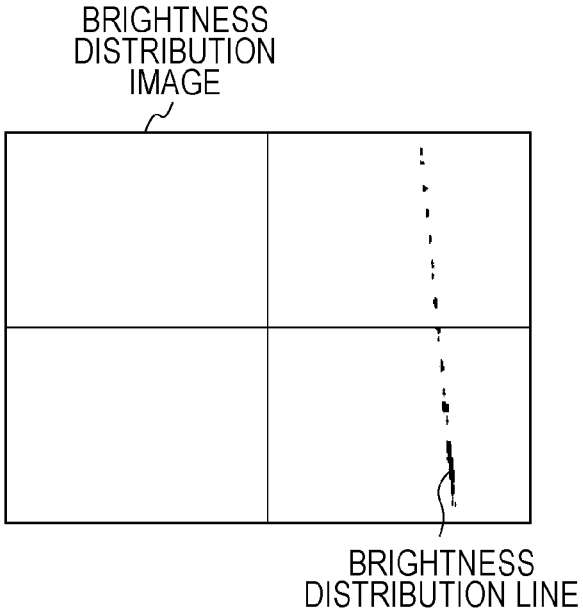

BRIGHTNESS DISTRIBUTION IMAGE
BRIGHTNESS DISTRIBUTION LINE

FIG. 9A

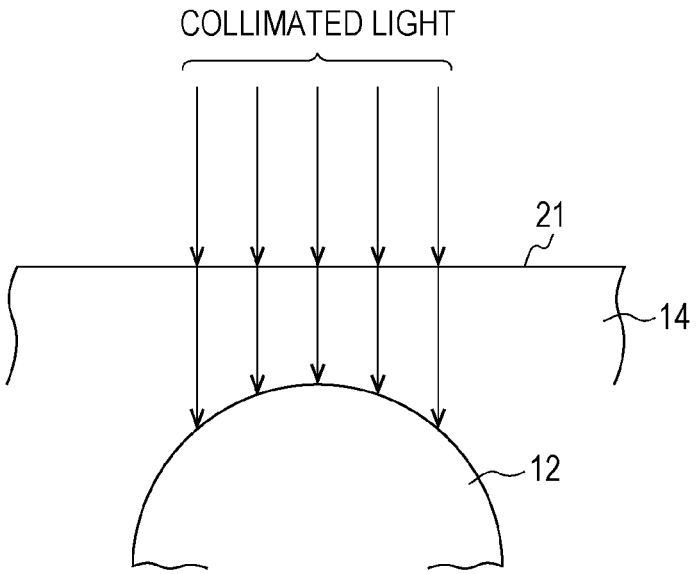


FIG. 9B

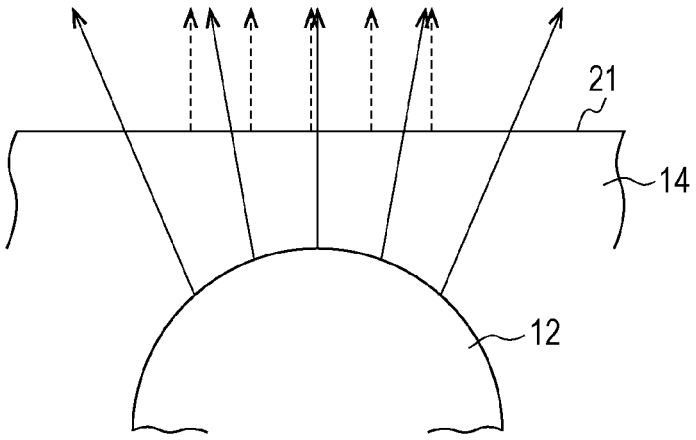


FIG. 10A

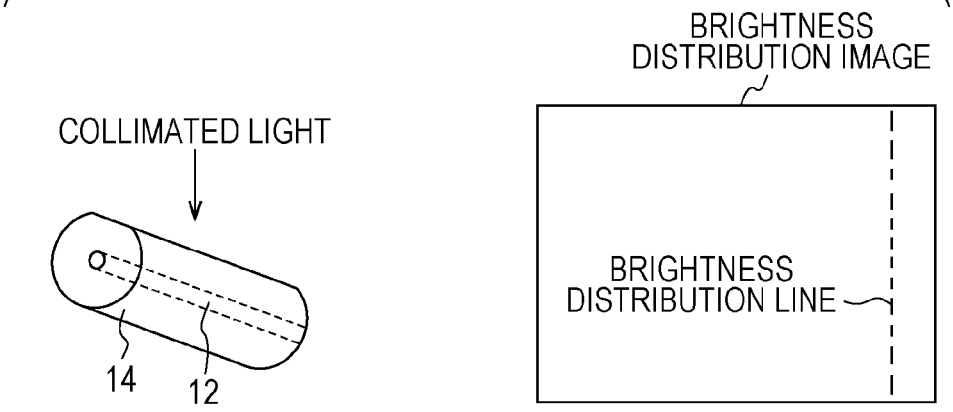


FIG. 10B

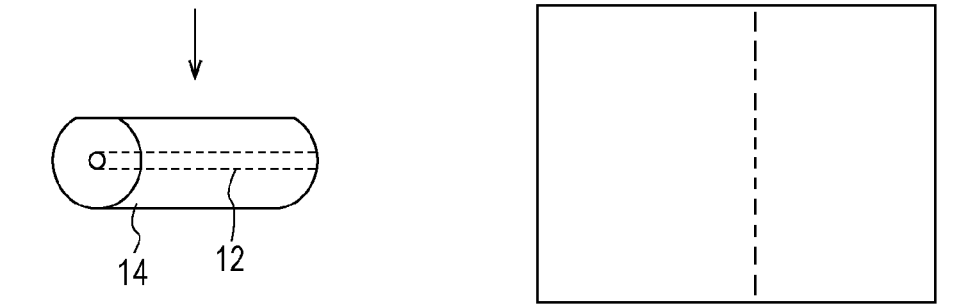


FIG. 10C

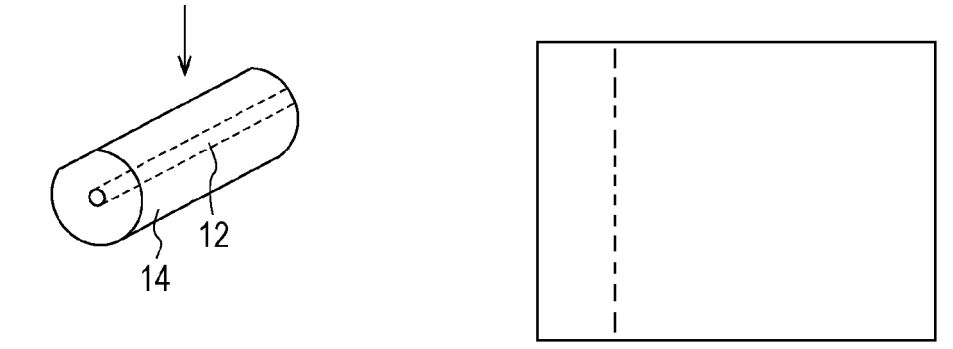


FIG. 11A

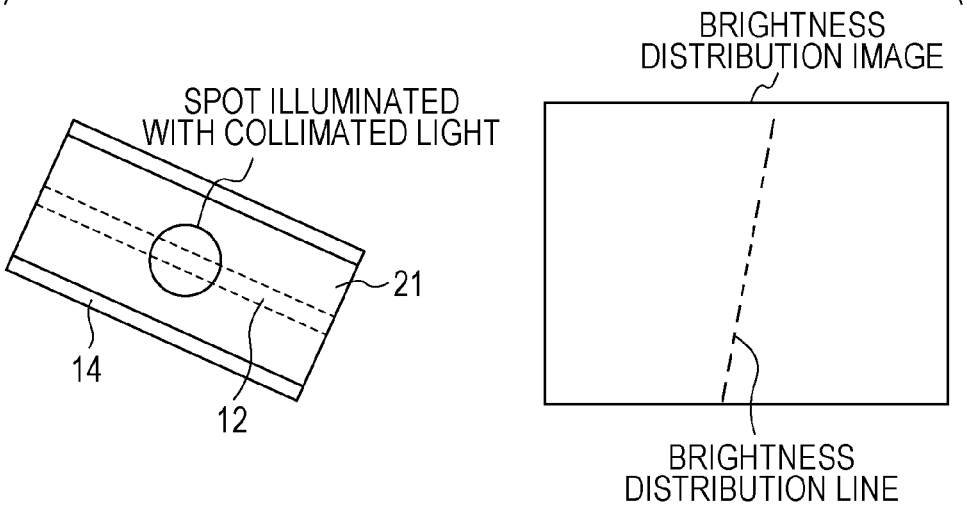


FIG. 11B

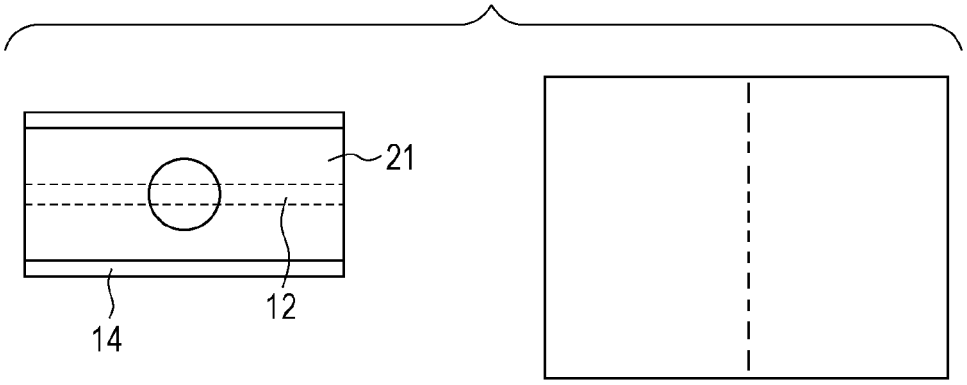


FIG. 11C

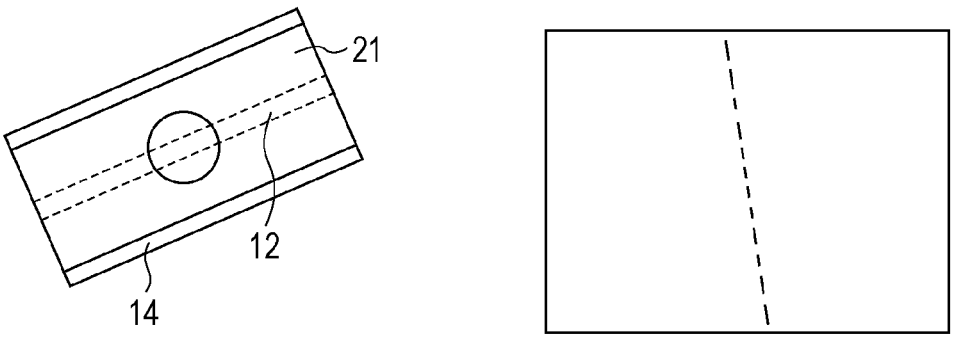


FIG. 12A

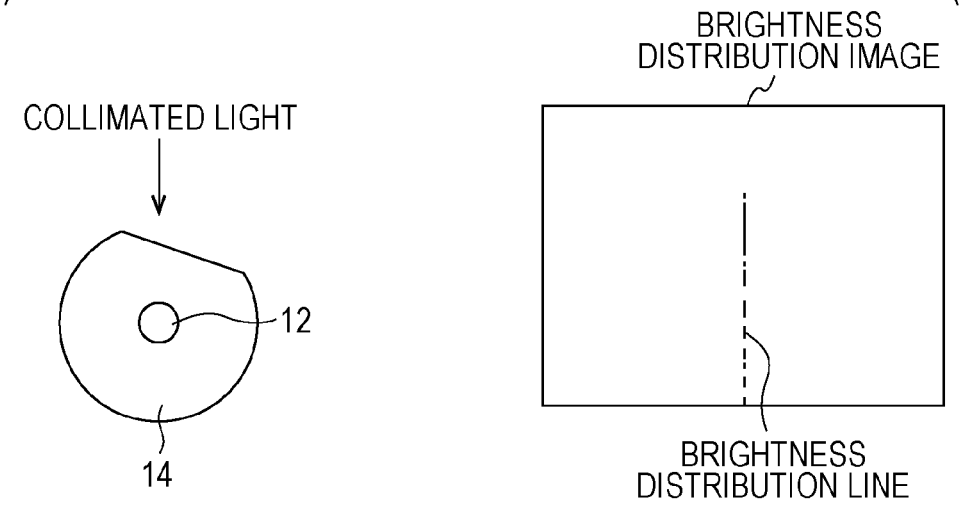


FIG. 12B

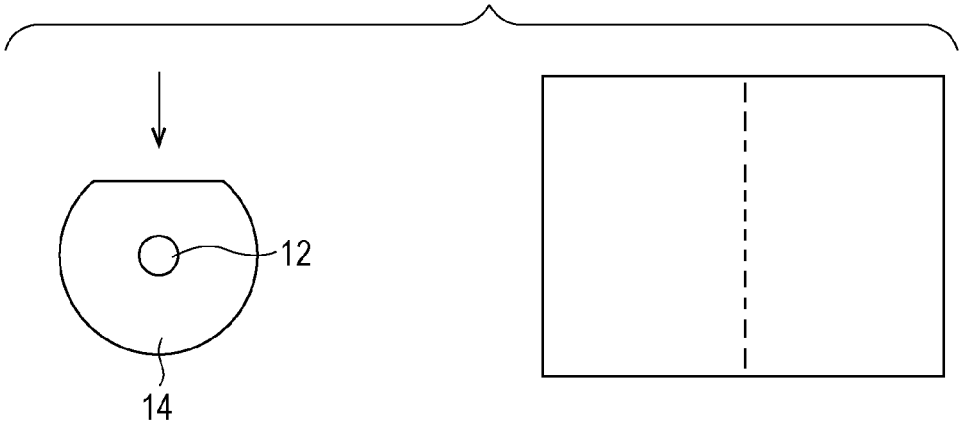


FIG. 12C

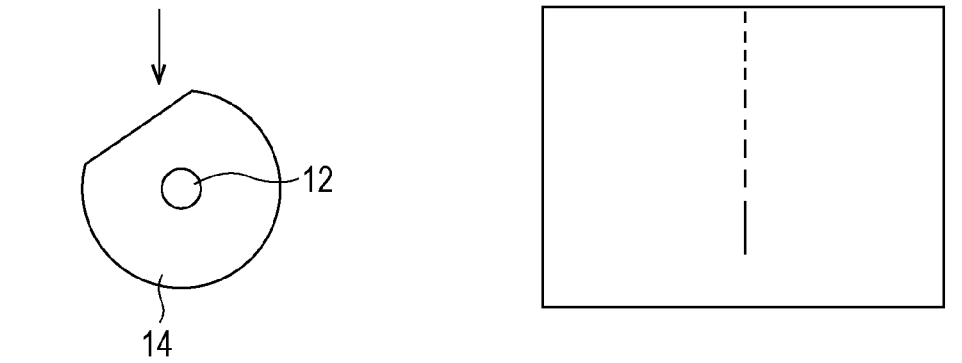


FIG. 13

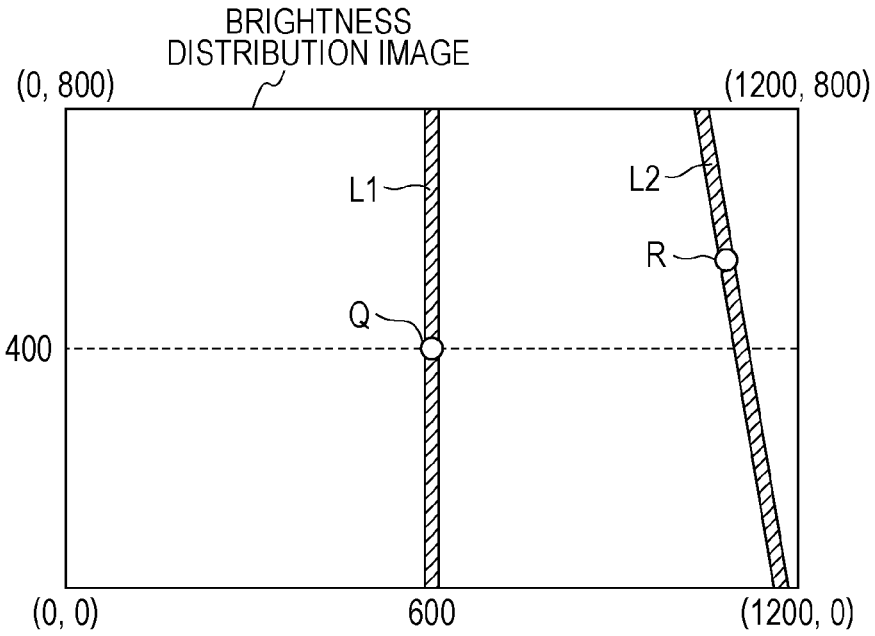

BRIGHTNESS
DISTRIBUTION IMAGE
(0, 800)
(1200, 800)
L1
L2
R
Q
400
(0, 0)
600
(1200, 0)

FIG. 14

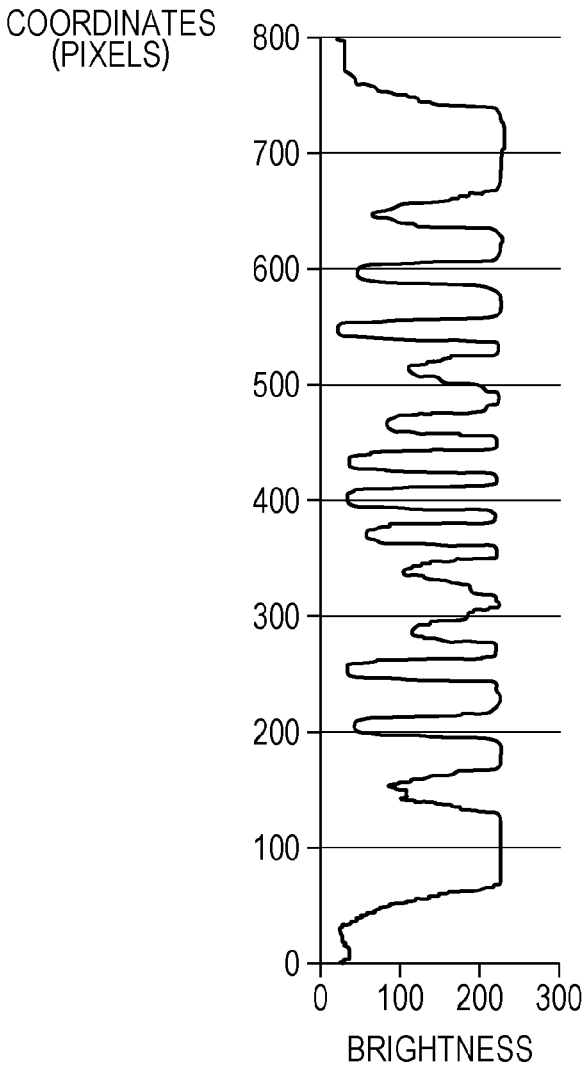

COORDINATES
(PIXELS)
800
700
600
500
400
300
200
100
0
0
100
200
300
BRIGHTNESS

FIG. 15

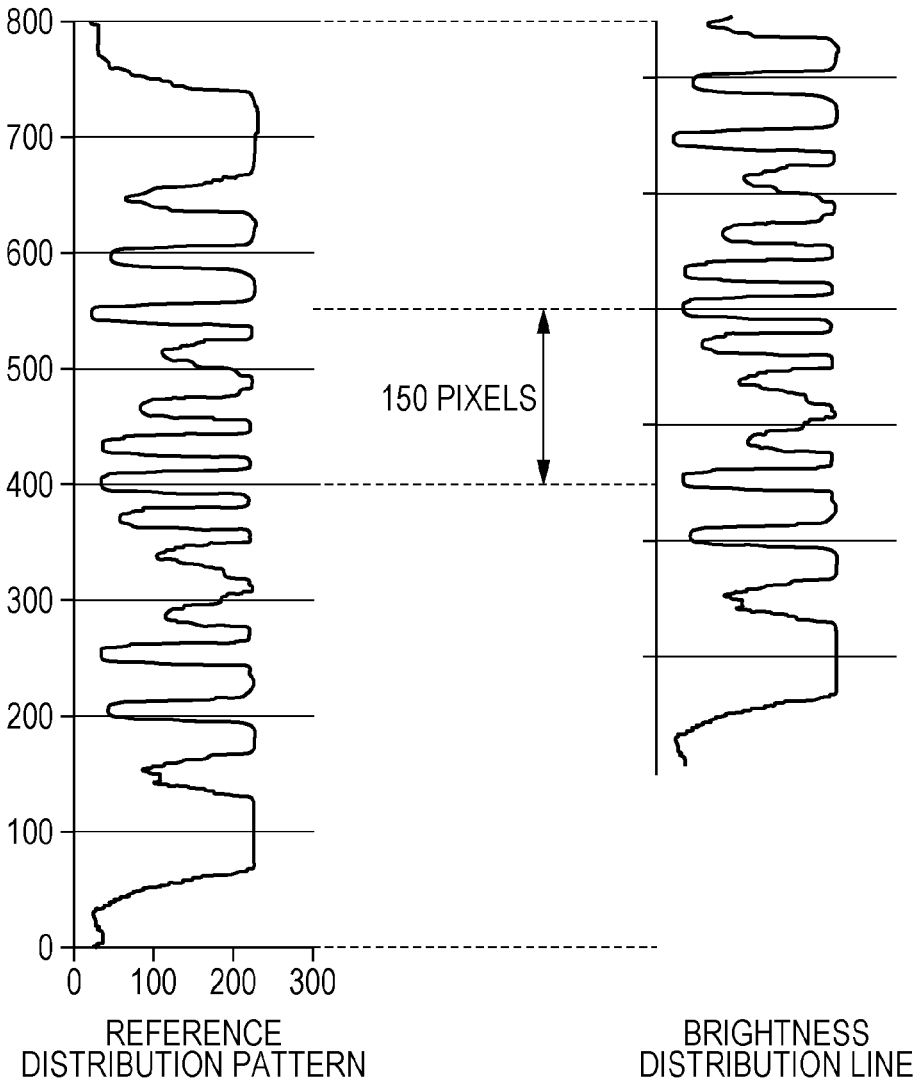

800
700
600
500
400
300
200
100
0
0
100
200
300
150 PIXELS
REFERENCE
DISTRIBUTION PATTERN
BRIGHTNESS
DISTRIBUTION LINE

FIG. 16

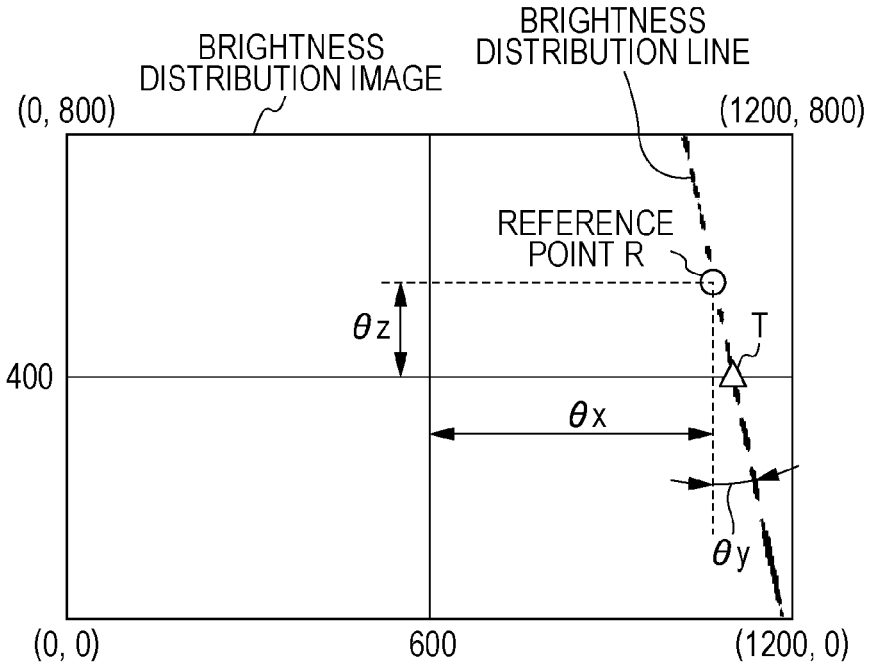

BRIGHTNESS DISTRIBUTION IMAGE
BRIGHTNESS DISTRIBUTION LINE
(0, 800)
(1200, 800)
REFERENCE POINT R
θz
T
400
θx
θy
(0, 0)
600
(1200, 0)

FIG. 17

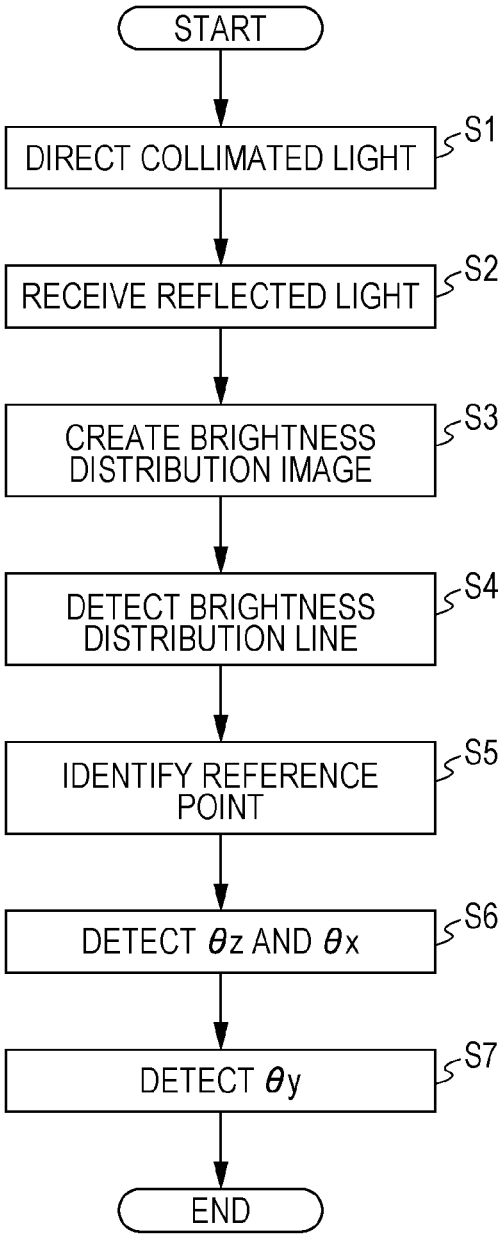
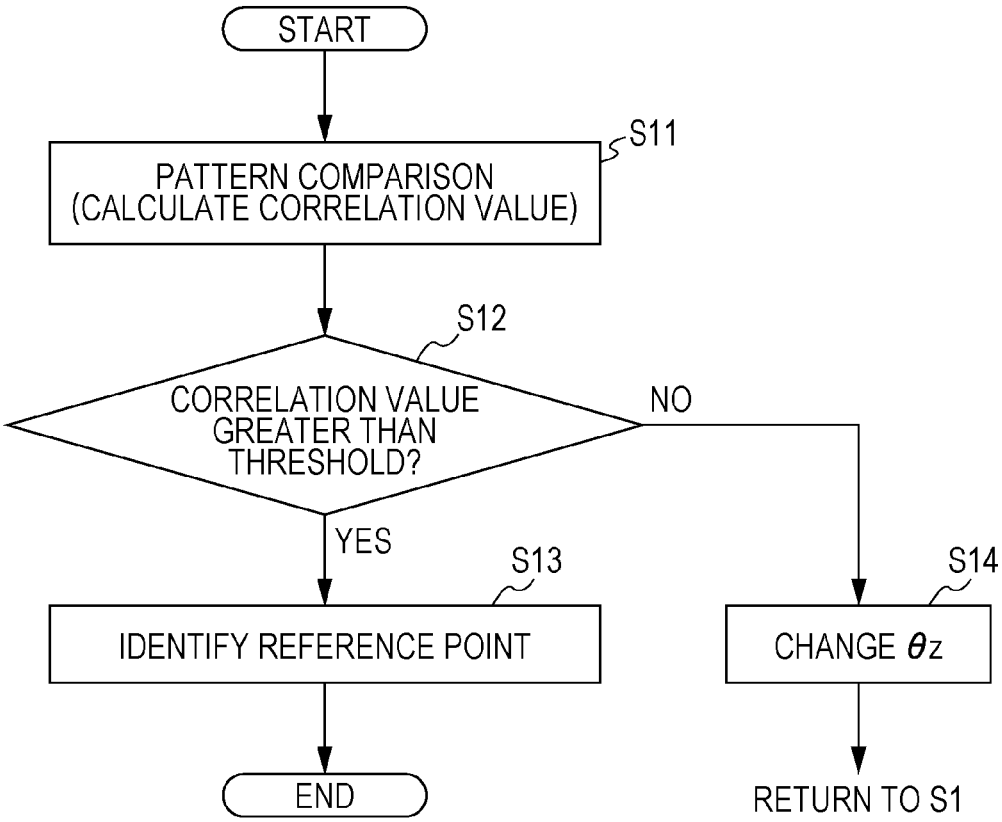

START
DIRECT COLLIMATED LIGHT
S1
RECEIVE REFLECTED LIGHT
S2
CREATE BRIGHTNESS DISTRIBUTION IMAGE
S3
DETECT BRIGHTNESS DISTRIBUTION LINE
S4
IDENTIFY REFERENCE POINT
S5
DETECT θz AND θx
S6
DETECT θy
S7
END

FIG. 18


START
S11
PATTERN COMPARISON
(CALCULATE CORRELATION VALUE)
S12
CORRELATION VALUE
GREATER THAN
THRESHOLD?
NO
YES
S13
IDENTIFY REFERENCE POINT
S14
CHANGE θz
END
RETURN TO S1

OPTICAL FIBER ORIENTATION DETECTION METHOD AND APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2012-278028, filed on Dec. 20, 2012, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to a method of detecting the orientation of an optical fiber and an apparatus.

BACKGROUND

Optical communication systems have come into widespread use and various types of optical modules are now in practical use. Examples of modules placed in practical use include modules including an optical modulator, an optical amplifier, an optical transmitter, an optical receiver, or an optical switch.

Commercially available optical modules include often an input optical fiber and an output optical fiber coupled thereto. The input optical fiber is optically coupled to the input end of an optical device such as, for example, an optical modulator, optical amplifier, optical transmitter, optical receiver, or optical switch in an optical module. The output fiber is optically coupled to the output end of the optical device. To reduce the coupling loss of the optical module, therefore, it is desirable to precisely align the ends of the input optical fiber and output optical fiber to the optical device.

When an optical module to which an optical fiber (an input optical fiber, an output optical fiber, or both) is connected is manufactured, the position of the end of the optical fiber is detected with respect to an optical device in the optical module. The position of the optical fiber is detected by, for example, using an electronic camera to photograph the optical fiber. The optical fiber is then aligned according to the detection result so as to reduce the coupling loss of the optical module.

As a related technology, a method is provided in which an optical part such as, for example, a waveguide, and an optical fiber are easily coupled with high precision (see Japanese Laid-open Patent Publication No. 8-146242, for example). In another method provided, the inclination of an end surface of a cylindrical member is highly precisely measured relative to the side surface of the cylindrical member (see Japanese Laid-open Patent Publication No. 2006-214753, for example). In still another method provided, a charge-coupled device (CCD) camera is used to inspect a defect on a thin film (see Japanese Laid-open Patent Publication No. 7-301608, for example).

SUMMARY

According to an aspect of the invention, a method of detecting an orientation of an optical fiber that is provided in an optical-transparent maintaining member including a flat surface as a part of a surface of the maintaining member, the method includes directing collimated light to the optical fiber through the flat surface of the maintaining member, receiving reflected light of the collimated light by using an optical sensor device, generating a brightness distribution image according to an output signal from the optical sensor device, identifying a reference point on a brightness distribution line appearing on the generated brightness distribution image, according to a position of the brightness distribution line in relation to a target orientation for the optical fiber, the brightness distribution line detectable on the brightness distribution image in correspondence to the reflected light received by the optical sensor device, and detecting the orientation of the optical fiber according to a coordinate of the reference point on the brightness distribution image.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates the orientation of an optical fiber;

FIGS. **2**A, **2**B, and **2**C illustrate θx, θy, and θz, which represent an orientation of the optical fiber;

FIGS. **3**A and **3**B illustrate an example of an optical module;

FIGS. **4**A and **4**B illustrate the structure of a ferrule;

FIG. **5** illustrates the structure of the orientation detecting apparatus;

FIGS. **6**A and **6**B illustrate a method in which an auto collimator is used to detect the orientation of a target object;

FIG. **7** illustrate light reflected when collimated light is directed to the optical fiber;

FIG. **8** illustrates an example of a brightness distribution image obtained when collimated light is directed to the optical fiber;

FIGS. **9**A and **9**B illustrate reflection from the optical fiber and ferrule;

FIGS. **10**A to **10**C illustrate examples of brightness distribution images generated with different θx values;

FIGS. **11**A to **11**C illustrate examples of brightness distribution images generated with different θy values;

FIGS. **12**A to **12**C illustrate examples of brightness distribution images created with different θz values;

FIG. **13** illustrates the orientation of the optical fiber and the position of a brightness distribution line;

FIG. **14** illustrates an example of a reference distribution pattern;

FIG. **15** illustrates an example of comparison;

FIG. **16** illustrates a method of calculating θx, θy, and θz according to a reference point;

FIG. **17** is a flowchart illustrating an orientation detection method in an embodiment; and

FIG. **18** is a flowchart illustrating a method of identifying the reference point.

DESCRIPTION OF EMBODIMENTS

Preliminary Consideration

To reduce the coupling loss in the optical module described in the background, it is desirable to appropriately adjust not only the position of the end of the optical fiber but also its orientation. The orientation of the optical fiber is represented by θx, θy, and θz illustrated in FIG. **1**.

In FIG. **1**, the optical fiber **1** is assumed to have been ideally aligned to an optical waveguide **3** formed in an optical device **2**. The origin of the xyz coordinate system in FIG. **1** is set at

the end of the optical fiber **1**. The z-axis indicates a propagation direction of optical signals. The x- and y-axes are each set on a plane the normal of which is the z-axis. The x- and y-axes are mutually orthogonal. The y-axis is set in a direction perpendicular to the mounting surface of the circuit board of the optical device **2**.

θx represents a rotational angle around the x-axis. FIG. **2**A illustrates a state in which the optical fiber **1** has been rotated through θx from a target orientation. In FIG. **2**A, the x-axis has been set in a direction perpendicular to the drawing sheet.

θy represents a rotational angle around the y-axis. FIG. **2**B illustrates a state in which the optical fiber **1** has been rotated through θy from the target orientation. In FIG. **2**B, the y-axis has been set in a direction perpendicular to the drawing sheet.

θz represents a rotational angle around the z-axis. FIG. **2**C illustrates a state in which the optical fiber **1** has been rotated through θz from the target orientation. In FIG. **2**C, the z-axis has been set in a direction perpendicular to the drawing sheet.

In the method in which an electronic camera is used to photograph the optical fiber, however, it is difficult to detect θx, θy, and θz. When, for example, the optical device **2** and optical fiber **1** are photographed from above the optical device **2**, it is difficult to detect θx and θz from image data obtained by the photography.

It may be possible to detect the orientation of the target object by using an auto collimator. The auto collimator directs collimated light to the target object and detects light reflected from the target object by using an optical sensor device such as, for example, a charge-coupled device (CCD) sensor. A brightness distribution image is generated according to output signals from the optical sensor device. When this brightness distribution image is analyzed, therefore, it may be possible to identify the position or orientation of the target object.

When, for example, collimated light with a certain beam diameter is directed to a flat surface of the target object, light reflected from the target object is also collimated light having substantially the same beam diameter. Accordingly, a high-brightness point appears at coordinates corresponding to a position at which the reflected light has been detected. The angle of the flat surface (or the direction of the normal to the flat surface) is detected according to the coordinates of the high-brightness point on the brightness distribution image and the orientation of the target objects thereby detected.

However, the optical fiber is formed in a thin, substantially rod shape. When collimated light with a certain beam diameter is directed to the optical fiber, therefore, light rays are led in different directions depending on the positions on the optical fiber to which the light rays have been directed. For this reason, a high-brightness point does not appear on the brightness distribution image. In the method in which collimated light reflected on a flat surface is used to detect the angle of the flat surface, it is difficult to detect the orientation of the optical fiber (that is, the set angle of the optical fiber).

Accordingly precisely detecting the orientation of an optical fiber is desired.

The embodiments will be described. FIGS. **3**A and **3**B illustrate an example of an optical module to which an orientation detection method in an embodiment of the present disclosure is applied. FIG. **3**A illustrates an optical module **10** as viewed from its side and FIG. **3**B illustrates the optical module **10** as viewed from above.

The optical module **10** includes an optical device chip **11**. An optical device is mounted on a surface of the optical device chip **11**. Although there is no particular restriction on the optical device, it is, for example, an optical modulator, optical amplifier, optical transmitter, optical receiver, optical switch, or other device. When an optical modulator is mounted on the surface of the optical device chip **11**, the optical device chip **11** is implemented by, for example, a Low Noise chip (LN chip). In this case, for example, an interferometer, a wire through which a driving signal is transferred, an electrode to which the driving signal is given, an optical waveguide, which is optically coupled to the interferometer, and the like are formed on the surface of the LN chip.

An input optical fiber **12***a* and an output optical fiber **12***b* are attached to the optical module **10**. The input optical fiber **12***a* is optically coupled to an input optical waveguide **13***a* of the optical device chip **11**. The output optical fiber **12***b* is optically coupled to an output optical waveguide **13***b* of the optical device chip **11**.

The end of the input optical fiber **12***a* is accommodated in a ferrule **14***a*. The ferrule **14***a* is secured to the optical device chip **11** with the input optical fiber **12***a* aligned to the input optical waveguide **13***a* of the optical device chip **11**. In this example, however, an auxiliary member (jig) **15***a* is attached to the surface of the optical device chip **11**. The ferrule **14***a* is secured to the optical device chip **11** and auxiliary member **15***a* with, for example, an adhesive.

Similarly, the end of the output optical fiber **12***b* is accommodated in a ferrule **14***b*. The ferrule **14***b* is secured to the optical device chip **11** with the output optical fiber **12***b* aligned to the output optical waveguide **13***b* of the optical device chip **11**. In this example, however, an auxiliary member (jig) **15***b* is attached to the surface of the optical device chip **11**. The ferrule **14***b* is secured to the optical device chip **11** and auxiliary member **15***b* with, for example, an adhesive.

In FIG. **3**A, the input optical waveguide **13***a* and output optical waveguide **13***b* are not illustrated. In FIG. **3**B, the auxiliary members **15***a* and **15***b* are not illustrated. In the description below, the input optical fiber **12***a* and output optical fiber **12***b* may be referred to as the optical fiber **12**, the input optical waveguide **13***a* and output optical waveguide **13***b* may be referred to as the optical waveguide **13**, and the ferrules **14***a* and **14***b* may be referred to as the ferrule **14**.

FIGS. **4**A and **4**B illustrate the structure of the ferrule **14**. FIG. **4**A is a perspective view of the ferrule **14**, and FIG. **4**B is a cross-sectional view of the ferrule **14**. The ferrule **14** is formed in a substantially cylindrical shape. However, an orientation flat **21** is formed on part of the side surface of the cylinder. The orientation flat **21** is a flat surface formed on the side surface of the ferrule **14** as an aid to detect the orientation of the ferrule **14**. The ferrule **14** accommodates the optical fiber **12** along the central axis of the cylinder. That is, the ferrule **14** is an example of a maintaining member that accommodates the optical fiber **12**. In FIG. **4**A, a through-hole **22** is drawn in which the optical fiber **12** is accommodated. The ferrule **14** is made of a transparent material. An example of the material of the ferrule **14** is glass. However, the ferrule **14** and the cladding of the optical fiber **12** have different refractive indexes.

Although there is no particular restriction on the optical fiber **12** accommodated in the ferrule **14**, the optical fiber **12** is a polarization maintaining fiber in this example. In this case, as illustrated in, for example, FIG. **4**B, the optical fiber **12** is accommodated in the ferrule **14** so that the polarization direction of the optical fiber **12** is substantially perpendicular to the orientation flat **21** of the ferrule **14**. Although there is no particular restriction on the optical fiber **12** accommodated in the ferrule **14** as described above, the optical fiber **12** is assumed not to be coated in this example. That is, the core and cladding of the optical fiber **12** are accommodated in the ferrule **14**.

The ferrule **14**, in which the optical fiber **12** is accommodated, is secured to the optical device chip **11** so that the

mounting surface of the optical device chip **11** and the orientation flat **21** of the ferrule **14** become parallel or substantially parallel to each other. Specifically, each ferrule **14** is secured to the optical device chip **11** and its corresponding auxiliary member **15***a* or **15***b* with an adhesive.

FIG. **5** illustrates the structure of an orientation detecting apparatus in an embodiment of the present disclosure. The orientation detecting apparatus **30** in the embodiment includes an auto collimator **31** and a processor system **34**. The auto collimator **31** includes a collimating unit **32** and an optical sensor device **33**. The collimating unit **32** includes a laser light source that generates laser light with a certain wavelength and also includes an optical system that generates collimated light with a certain beam diameter from the laser light. The collimated light generated by the collimating unit **32** is directed to the target object to be detected. The target object to be detected is the optical waveguide fiber **12** (that is, the input optical fiber **12***a* and output optical fiber **12***b* of the optical module **10**).

The optical sensor device **33** receives the light reflected on the optical fiber **12** where the light is the collimated light generated by the collimating unit **32**. Since the optical fiber **12** is accommodated in the transparent ferrule **14**, the optical sensor device **33** receives reflected light from the optical fiber **12** and reflected light from the ferrule **14**. The optical sensor device **33** is implemented by, for example, a CCD sensor or a complementary metal oxide semiconductor (CMOS) sensor.

The processor system **34** includes a brightness-distribution-image creating unit **35** and an orientation detector **36**. The brightness-distribution-image creating unit **35** creates a brightness distribution image according to the output signal from the optical sensor device **33**. The orientation detector **36** detects the orientations of the optical fibers **12** (**12***a* and **12***b*) according to the brightness distribution image created by the brightness-distribution-image creating unit **35**. The processor system **34** provides functions of the brightness-distribution-image creating unit **35** and orientation detector **36** by, for example, executing a software program. In this case, the software program is stored in, for example, a memory provided in the processor system **34** or a memory accessible to the processor system **34**.

The processor system **34** includes a brightness-distribution database **37**. The brightness-distribution database **37** stores data that represents a reference distribution pattern, which will be described later. The brightness-distribution database **37** may be disposed outside the processor system **34**. In this case, the brightness-distribution database **37** accesses the brightness-distribution database **37** and obtains the reference distribution pattern.

Although, in the example illustrated in FIG. **5**, the processor system **34** creates the brightness distribution image, the present disclosure is not limited to this configuration or structure. For example, the auto collimator **31** may include a function that generates the brightness distribution image, and the processor system **34** may use the brightness distribution image generated by the auto collimator **31** to detect the orientation of the optical fiber **12**. In this case, the processor system **34** may lack the brightness-distribution-image creating unit **35**.

The alignment apparatus **40** adjusts the positions and orientations of the optical fibers **12** (**12***a* and **12***b*). During this adjustment, the alignment apparatus **40** places the optical module **10** below the auto collimator **31**. That is, the optical module **10** is placed so that collimated light is directed from above the auto collimator **31** to the optical fiber **12** and ferrule **14**. In the adjustment of the positions of the fibers **12***a* and output optical fiber **12***b*, the alignment apparatus **40** respectively aligns the ends of the fibers **12***a* and **12***b* to their corresponding optical waveguides **13***a* and **13***b*. In the adjustment of the orientations of the input optical fiber **12***a* and input optical fiber **12***b*, the alignment apparatus **40** references the detection result obtained from the orientation detecting apparatus **30**.

Depending on the structure of the optical module **10**, collimated light may be directed to the optical module **10** only from one direction. To simplify a manufacturing process of the optical module **10**, it is desirable to detect the orientation of the optical fiber **12** by directing collimated light to the optical module **10** from the one direction. For these reasons, in the orientation detection method in the embodiment, the orientation of the optical fiber **12** is detected by directing collimated light to the optical fiber **12** from the one direction. In this example, when the orientation of the optical fiber **12** is detected, the optical module **10** is placed below the auto collimator **31** as illustrated in FIG. **3**A. That is, when the orientation of the optical fiber **12** is detected, the optical module **10** receives collimated light from above.

The orientation detecting apparatus **30** may concurrently detect the orientations of the fibers **12***a* and **12***b* to adjust their orientations. Alternatively, the orientation detecting apparatus **30** may detect the orientations of the fibers **12***a* and **12***b* one at a time to adjust their orientations.

FIGS. **6**A and **6**B illustrate a method in which the auto collimator **31** is used to detect the orientation of the target object. In this example, collimated light having a certain beam diameter is directed to the flat surface, as illustrated in FIG. **6**A. In this case, light reflected from the target object is also collimated light having substantially the same beam diameter. Accordingly, when the optical sensor device **33** receives the reflected light of the collimated light, a high-brightness point corresponding to the reflected light appears on the brightness distribution image, as illustrated in FIG. **6**B. The coordinates of this high-brightness point correspond to the position at which the optical sensor device **33** has detected the reflected light. Accordingly, the coordinates of the high-brightness point represent the orientation of the target object. When, for example, it is assumed that the xyz ordinate system illustrated in FIG. **6**A has been defined and collimated light parallel to the y-axis is directed to the target object, then coordinate θx in the horizontal direction on the brightness distribution image represents an angle through which the target object has been rotated around the x-axis. Similarly, coordinate θz in the horizontal direction on the brightness distribution image represents an angle through which the target object has been rotated around the z-axis. The auto collimator **31** is be used to detect the orientation of the target object in this way.

FIG. **7** illustrate light reflected when collimated light is directed to the optical fiber **12**. The optical fiber **12** is formed in a cylindrical or substantially cylindrical shape with a certain diameter. The collimated light has a certain beam diameter. Accordingly, light rays are led in different directions depending on the positions, on the side surface of the optical fiber **12**, to which the light rays have been directed, as illustrated in FIG. **7**. For example, reflected light of a collimated light ray directed to point P**1** is led to angle θ**1**. Similarly, reflected light of a collimated light ray directed to point P**2** is led to angle θ**2**, and reflected light of a collimated light ray directed to point P**3** is led to angle θ**3**. When the optical axial direction of the optical fiber **12** is the z direction, the z coordinates at points P**1** to P**3** are the same.

The reflected light of the collimated light is received by the optical sensor device **33**. Specifically, the reflected light rays of the collimated light rays are led on a single straight line on

the light receiving surface of the optical sensor device **33**. For example, the reflected light rays from points P**1** to P**3** are respectively led to points Q**1** to Q**3** on the optical sensor device **33**. Points Q**1** to Q**3** are aligned on a straight line S.

Collimated light rays may be directed to positions having the same rotational angle ϕ illustrated in FIG. **7**. Even when these collimated light rays are directed to different positions in the optical axial direction (z direction in FIG. **7**) of the optical fiber **12**, the reflected light rays of the collimated light rays are led substantially in the same direction. For example, points P**2** and P**4** have the same rotational angle ϕ relative to the center of the optical fiber **12**. In this case, a reflected light ray from point P**2** and a reflected light ray from point P**4** are led in the same direction. Accordingly, the reflected light ray of the collimated light ray directed to point P**4** is led to a point near point Q**2** on the optical sensor device **33**. When collimated light having a certain beam diameter is directed to the side surface of the optical fiber **12**, therefore, reflected light rays are not detected along the straight line S on the optical sensor device **33**.

FIG. **8** illustrates an example of a brightness distribution image obtained when collimated light is directed to the optical fiber **12**. In FIG. **8**, high-brightness pixels are represented in black.

The brightness distribution image is created according to output signals from the optical sensor device **33**, as described above. The reflected light from the optical fiber **12** is detected by the optical sensor device **33** along the straight line S. On the brightness distribution image, therefore, a brightness distribution pattern corresponding to the reflected light forms a substantially straight line. That is, a substantially straight brightness distribution pattern is obtained on the brightness distribution image. In the description below, a linear brightness distribution pattern, which appears on the brightness distribution image due to reflected light, may be referred to as a brightness distribution line.

As described above, the optical fiber **12** is accommodated in the ferrule **14**. That is, the collimated light is directed through the ferrule **14** to the optical fiber **12**, as illustrated in FIG. **9**A. Specifically, the collimated light is directed to the orientation flat **21** of the ferrule **14**. The collimated light is assumed to be directed substantially perpendicular to the orientation flat **21**.

When directed to the optical fiber **12**, therefore, the collimated light is also reflected by the ferrule **14** as illustrated in FIG. **9**B. In FIG. **9**B, the solid arrows represent reflected light rays from the optical fiber **12** and the dotted arrows represent reflected light rays from the ferrule **14**. The reflected light from the ferrule **14** is also led to the optical sensor device **33**. The reflected light from the optical fiber **12** and the reflected light from the ferrule **14** mutually interfere. When collimated light is directed to the optical fiber **12**, therefore, the brightness distribution line, which appears on the brightness distribution image due to reflected light, has an interference fringe as illustrated in FIG. **8**. The interference fringe pattern of the brightness distribution line is determined according to the diameter and material of the optical fiber **12**, the shape and material of the ferrule **14**, and other properties.

As described above, the orientation detecting apparatus **30** in the embodiment directs collimated light to the optical fiber **12** accommodated in the ferrule **14** and detects reflected light of the collimated light by using the optical sensor device **33**. The orientation detecting apparatus **30** then creates a brightness distribution image from output signals supplied from the optical sensor device **33**. Therefore, the orientation detecting apparatus **30** detect the orientation of the optical fiber **12** according to the brightness distribution line appearing on the brightness distribution image.

Next, relationships between the brightness distribution and the orientation of the optical fiber **12** will be described with reference to FIGS. **10**A to **10**C, **11**A to **11**C, and **12**A to **12**C. It will be assumed here that the xyz coordinate system illustrated in FIGS. **1** and **2**A to **2**C has been set. Collimated light parallel to the y-axis is assumed to be directed to the optical fiber **12** and ferrule **14**. The optical fiber **1** and optical device **2** in FIGS. **1** and **2**A to **2**C correspond to the optical fiber **12** (**12***a* and **12***b*) and the optical device chip **11**.

FIGS. **10**A to **10**C illustrate examples of brightness distribution images generated with different θx values. θx represents a rotational angle around the x-axis as in FIG. **1**. That is, θx represents an inclination angle of the optical fiber **12** as in FIG. **2**A. Specifically, θx represents an inclination angle of the optical fiber **12** relative to a plane the direction of the normal of which is the propagation direction of the collimated light. The brightness distribution images in FIGS. **10**A to **10**C have been obtained when θy is 0 and θz is 0.

FIG. **10**B illustrates a brightness distribution image generated when θx is 0. When θx is 0, this state is equivalent to a state in which the optical fiber **12** is maintained at the target orientation with respect to angle θx. Specifically, when θx is 0, this state is equivalent to a state in which the optical fiber **12** is maintained parallel to the mounting surface of the optical device chip **11**. In this state, a brightness distribution line appears at the center of the brightness distribution image.

FIG. **10**A illustrates a brightness distribution image generated when the optical fiber **12** is inclined in the negative direction (θx=−0.5 degree). In this state, a brightness distribution line appears on the right side when compared with the brightness distribution line generated when θx is 0. FIG. **10**C illustrates a brightness distribution image generated when the optical fiber **12** is inclined in the positive direction (θx=0.5 degree). In this state, a brightness distribution line appears on the left side when compared with the brightness distribution line generated when θx is 0.

When θx changes, the position (coordinate of the brightness distribution image in the horizontal direction) at which a brightness distribution line appears changes in this way. That is, the position (coordinate of the brightness distribution image in the horizontal direction) at which a brightness distribution line appears is determined by θx.

FIGS. **11**A to **11**C illustrate examples of brightness distribution images generated with different θy values. θy represents a rotational angle around the y-axis as in FIG. **1** or FIG. **2**B. That is, θy represents an angle of the optical fiber **12** in a certain direction on a plane the direction of the normal of which is the propagation direction of the collimated light. The brightness distribution images in FIGS. **11**A to **11**C have been obtained when θx is 0 and θz is 0.

FIG. **11**B illustrates a brightness distribution image generated when θy is 0. When θy is 0, this state is equivalent to a state in which the optical fiber **12** is maintained at the target orientation with respect to angle θy. In this state, a brightness distribution line appears so as to extend in the vertical direction (or perpendicular direction) of the brightness distribution image.

FIG. **11**A illustrates a brightness distribution image generated when θy is −10 degrees. In this state, the brightness distribution line is inclined to the right. FIG. **11**C illustrates a brightness distribution image generated when θy is 10 degrees. In this state, the brightness distribution line is inclined to the left.

When θy changes, the inclination of the brightness distribution line changes in this way. That is, the inclination of the brightness distribution line is determined by θy.

FIGS. **12**A to **12**C illustrate examples of brightness distribution images generated with different θz values. θz represents a rotational angle around the z-axis as in FIG. **1**. That is, θz represents a rotational angle of the optical fiber **12** relative to the optical axis of the optical fiber **12**, as in FIG. **2**C. The brightness distribution images in FIGS. **12**A to **12**C have been obtained when θx is 0 and θy is 0.

FIG. **12**B illustrates a brightness distribution image generated when θz is 0. When θz is 0, this state is equivalent to a state in which the optical fiber **12** is maintained at the target orientation with respect to angle θz. Specifically, when θz is 0, this state is equivalent to a state in which the direction of a polarized wave maintained by the optical fiber **12** matches a predetermined direction.

FIG. **12**A illustrates a brightness distribution image generated when θz is −0.5 degree. In this state, a brightness distribution line appears below when compared with the brightness distribution line generated when θz is 0. FIG. **12**C illustrates a brightness distribution image generated when θz is 0.5 degree. In this state, a brightness distribution line appears above when compared with the brightness distribution line generated when θz is 0.

When θz changes, the position (coordinate of the brightness distribution image in the perpendicular direction) at which a brightness distribution line appears changes in this way. That is, the position (coordinate of the brightness distribution image in the perpendicular direction) at which a brightness distribution line appears is determined by θz.

The orientation detecting apparatus **30** in the embodiment uses the relationships described above to detect the orientation of the optical fiber **12**. Specifically, the orientation detecting apparatus **30** detects the orientation of the optical fiber **12** according to the position and inclination angle of the brightness distribution line that appears on the brightness distribution image.

In the orientation detection method in the embodiment, the target orientation of the optical fiber **12** is specified. For example, the target orientation of the optical fiber **12** is specified as described below.

(1) The optical fiber **12** is placed on a plane that is parallel to the mounting surface of the optical device chip **11**. This condition is stipulating by setting θx to 0.

(2) The optical fiber **12** is placed so as to extend in the same direction as the direction in which the input optical waveguide **13** (input optical waveguide **13***a* or output optical waveguide **13***b*) of the optical device chip **11** propagates light. This condition is stipulating by setting θy to 0.

(3) The direction of the polarized wave maintained by the optical fiber **12** is perpendicular to the mounting surface of the optical device chip **11**. This condition is stipulating by setting θz to 0.

The orientation detecting apparatus **30** detects the orientation of the optical fiber **12** with respect to the above target orientation. In this case, when the orientation detector **36** detects the relative position (coordinate in the horizontal direction) of the brightness distribution line appearing on the brightness distribution image, with respect to the brightness distribution line corresponding to the target orientation illustrated in FIG. **10**B, θx be calculated. When the orientation detector **36** detects the relative inclination angle of the brightness distribution line appearing on the brightness distribution image, with respect to the brightness distribution line corresponding to the target orientation illustrated in FIG. **11**B, θy be calculated. When the orientation detector **36** detects the relative position (coordinate in the perpendicular direction) of the brightness distribution line appearing on the brightness distribution image, with respect to the brightness distribution line corresponding to the target orientation illustrated in FIG. **12**B, θz be calculated.

FIG. **13** illustrates the orientation of the optical fiber **12** and the position of the brightness distribution line. The line L**1** represents the brightness distribution line obtained when the optical fiber **12** is maintained in the target orientation. As illustrated in FIG. **13**, the line L**1** is positioned at the center of the brightness distribution image in the horizontal direction. The line L**1** also extends on the brightness distribution image in the perpendicular direction. The orientation detecting apparatus **30** is set so that when the optical fiber **12** is maintained in the target orientation, the line L**1** is obtained.

The line L**2** represents the brightness distribution line obtained when collimated light is directed to the optical fiber **12**. The line L**2** is obtained by having the line L**1** undergo parallel displacement from a point Q to a point R and then inclining the line L**1**. Parallel displacement from the point Q to the point R is achieved when angles θx and θz are given to the optical fiber **12**. The brightness distribution line to be inclined when angle θy is given to the optical fiber **12**.

Accordingly, to detect θx and θz, the orientation detecting apparatus **30** detects parallel displacement from the point Q to the point R on the brightness distribution image. In this example, the point Q is set at the central coordinates (600, 400) of the brightness distribution image. Therefore, the orientation detecting apparatus **30** identifies the coordinates of the point R to detect θx and θz. θx and θz will be calculated by using the point R on the non-aligned optical fiber **12** which is represented by L**2**, and accordingly the point R will be referred to below as the reference point.

To identify the reference point described above, the orientation detector **36** compares the brightness distribution line appearing on the brightness distribution image with the reference distribution pattern L**1**, which is prepared in advance. The orientation detector **36** identifies the coordinates of the reference point used to calculate θz and θx, according to the comparison result.

FIG. **14** illustrates an example of the reference distribution pattern. The reference distribution pattern represents a brightness distribution (interference fringe pattern) obtained when collimated light is directed to the optical fiber **12** maintained in a predetermined orientation. In FIG. **14**, the vertical axis represents coordinates of the brightness distribution image in the perpendicular direction. In this example, the size of the brightness distribution image is 800×1200 pixels as illustrated in FIG. **13**, so 0 indicates the pixel at the lower end of the brightness distribution image and 800 indicates the pixel at the upper end. The horizontal axis indicates brightness. In this example, the brightness of each pixel is represented by eight-bit data (one of 0 to 255).

The reference distribution pattern represents a brightness distribution obtained in correspondence to the reflected light from the optical fiber **12** and the reflected light from the ferrule **14** when, for example, the optical fiber **12** is adjusted to a target orientation. That is, the reference distribution pattern represents an interference fringe pattern of a brightness distribution line obtained in correspondence to reflected light when the optical fiber **12** is adjusted to the target orientation. The target orientation of the optical fiber **12** in this example is represented by θx=0, θy=0, and θz=0. In the example in FIG. **13**, the reference distribution pattern is the line L**1**.

When collimated light is directed through the orientation flat **21** of the ferrule **14** to the optical fiber **12**, a distribution of angles at which reflected light rays are led is substantially

symmetrical with respect to the center of the distribution, as illustrated in FIG. **9**B. Accordingly, the interference fringe pattern of the brightness distribution corresponding to the reflected light from the optical fiber **12** and the reflected light from ferrule **14** is also substantially symmetrical with respect to the center of the pattern. When the optical fiber **12** is maintained in the target orientation, the interference fringe pattern of the brightness distribution is symmetric with respect to the center of the brightness distribution image. On the reference distribution pattern in FIG. **14**, therefore, a brightness distribution image from coordinate 400 to coordinate 800 and a brightness distribution image from coordinate 400 to coordinate 0 are substantially symmetric with each other.

The reference distribution pattern is generated in advance through, for example, a measurement or simulation. The interference fringe pattern of the brightness distribution line obtained when collimated light is directed to the optical fiber **12** is determined according to the diameter and material of the optical fiber **12**, the shape and material of the ferrule **14**, and other properties. Data representing the reference distribution pattern is stored in the brightness-distribution database **37**.

The orientation detector **36** obtains brightness distribution data representing the brightness distribution line that has appeared on the brightness distribution image. The orientation detector **36** then compares the brightness distribution line appearing on the brightness distribution image with the reference distribution pattern, as illustrated in FIG. **15**. In this comparison, the orientation detector **36** shifts the reference distribution pattern, for example, one pixel at a time and calculates a correlation between the interference fringe of the reference distribution pattern and the interference fringe of the brightness distribution line for each shift. In the example in FIG. **15**, when the reference distribution pattern is shifted 150 pixels, the brightness distribution image substantially matches the reference distribution pattern. In this case, the orientation detector **36** identifies the reference point according to a shift of 150 pixels.

FIG. **16** illustrates a method of calculating θx, θy, and θz according to the reference point. The coordinates of the reference point are determined according to the result of comparison between the brightness distribution line and the reference distribution pattern. In an example, a start point T on the brightness distribution image is first determined. The start point T is an intersection between the brightness distribution line and a straight line representing a perpendicular coordinate of 400. When a shift of 150 pixels has been obtained in the comparison in FIG. **15**, a point at a distance of 150 pixels from the start point T on the brightness distribution line is identified as the reference point R.

The orientation detector **36** calculates θz and θx on the brightness distribution image from the coordinates of the reference point R; θz and θx are represented by $\theta z=Kz\times Rz$ and $\theta x=Kx\times Rx$, where Rz represents the coordinate of the reference point in the perpendicular direction, Rx represents the coordinate of the reference point R in the horizontal direction, and Kz and Kx each represent a proportional coefficient. These proportional coefficients are obtained in advance through, for example, a measurement or simulation.

The orientation detector **36** detects θy on the brightness distribution image according to the inclination angle of the brightness distribution line. In this example, the inclination angle of the brightness distribution line matches θy. Accordingly, θy be detected by calculating the inclination angle of the brightness distribution line.

FIG. **17** is a flowchart illustrating the orientation detection method in the embodiment. Processing in this flowchart is executed when a command to detect the orientation of the optical fiber **12** is issued to the orientation detecting apparatus **30**. The position of the optical fiber **12** is assumed to have been appropriately adjusted so that the optical fiber **12** and its corresponding input optical waveguide **13** are optically coupled before this flowchart is executed.

In S**1**, the auto collimator **31** uses the collimating unit **32** to direct collimated light to the optical fiber **12**. Since the optical fiber **12** is accommodated in the ferrule **14**, the collimated light is directed through the ferrule **14** to the optical fiber **12**. In this case, the collimated light is directed substantially perpendicular to the orientation flat **21** of the ferrule **14**, in which the optical fiber **12** is accommodated.

In S**2**, the auto collimator **31** uses the optical sensor device **33** to receive reflected light of the collimated light. In this case, the optical sensor device **33** receives reflected light from the optical fiber **12** and reflected light from the orientation flat **21** of the ferrule **14**.

In S**3**, the brightness-distribution-image creating unit **35** creates a brightness distribution image according to output signals from the optical sensor device **33**. When the collimated light is directed to the optical fiber **12** (and the ferrule **14**), a brightness distribution line appears on the brightness distribution image. The brightness distribution line is generated from the reflected light detected in S**2**.

In S**4**, the orientation detector **36** detects the brightness distribution line appearing on the brightness distribution image generated in S**3**. The orientation detector **36** also obtains data representing the coordinates and brightness of each pixel on the brightness distribution line.

In S**5**, the orientation detector **36** identifies the coordinates of the reference point on the brightness distribution image according to positions of the brightness distribution line appearing on the brightness distribution image. The method of identifying the coordinates of the reference point according to points of the brightness distribution line is as described above with reference to, for example, FIGS. **14** to **16**.

In S**6**, the orientation detector **36** detects θz and θx according to the coordinates of the reference point. In S**7**, the orientation detector **36** detects θy according to the inclination angle of the brightness distribution line on the brightness distribution image. Processing in S**7** may be executed between S**4** and S**5** or between S**5** and S**6**.

FIG. **18** is a flowchart illustrating a method of identifying the reference point. Processing in this flowchart is an example of processing in S**5** in FIG. **17**.

In S**11**, the orientation detector **36** compares the brightness distribution line extracted from the brightness distribution image with the reference distribution pattern. Specifically, the orientation detector **36** calculates a correlation between data representing the brightness distribution line and data representing the reference distribution pattern. When, for example, the reference distribution pattern is shifted one pixel at a time and a correlation is calculated between the brightness distribution line and the reference distribution pattern for each shift, a shift at which the maximum correlation value is obtained is stored.

In S**12**, the orientation detector **36** compares the correlation value calculated in S**11** (in the above example, the maximum correlation value) with a predetermined threshold. When the correlation value is larger the threshold, in S**13** the orientation detector **36** identifies the coordinates of the reference point according to the position of the interference fringe of the brightness distribution line.

When the correlation value is smaller than or equal to the threshold, in S**14** the orientation detector **36** commands the alignment apparatus **40** to change the value of θz. The align-

ment apparatus **40** adjusts the value of θz of the optical fiber **12** in response to the command from the orientation detector **36**. Processing in the orientation detecting apparatus **30** then returns to S**1**. Thus, after a brightness distribution line preferable in detection of the orientation of the optical fiber **12** has been obtained, the orientation detecting apparatus **30** detects the orientation of the optical fiber **12**.

In the orientation detection method in the embodiment, the orientation of an optical fiber that is optically coupled to an optical device may be detected by using an auto collimator and image processing. In the orientation detection method in the embodiment, the orientation of an optical fiber may be detected even when light is directed to the optical fiber only in one direction.

Another Embodiment

The coordinates of the reference point R may be identified by another method. For example, on the brightness distribution image, the orientation detector **36** may compare the brightness distribution line with the reference distribution pattern illustrated in FIG. **14**. In this comparison, the orientation detector **36** detects a pixel corresponding to a coordinate of 400 on the reference distribution pattern (or a pixel corresponding to the point Q on the line L**1** illustrated in FIG. **13**) on the brightness distribution line. The orientation detector **36** then uses the pixel detected as described above as the reference point.

Alternatively, the orientation detector **36** may identify the reference point by using the symmetry of the interference fringe of the brightness distribution line. In this method, the orientation detector **36** identifies, as the reference point, a point with respect to which the interference fringe of the brightness distribution line is symmetrical.

In still another method, a brightness distribution image is generated for each of two different θz angles. For example, when collimated light is directed to the vicinity of edges on the both sides of the orientation flat **21**, a brightness distribution image is generated for each edge. The reference point is identified according to the position of the brightness distribution line appearing on each brightness distribution image.

In the embodiments described above, the ferrule **14** has been shaped in a cylindrical form. However, the present disclosure is not limited to this structure. It suffices that the maintaining member that accommodates the optical fiber has a flat surface as at least part of the surface of the maintaining member.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A method of detecting an orientation of an optical fiber that is provided in an optical-transparent maintaining member including a flat surface as a part of a surface of the maintaining member, the method comprising:

directing collimated light to the optical fiber through the flat surface of the maintaining member;

receiving reflected light of the collimated light by using an optical sensor device;

generating a brightness distribution image according to an output signal from the optical sensor device;

identifying a reference point on a brightness distribution line appearing on the generated brightness distribution image, according to a position of the brightness distribution line in relation to a target orientation for the optical fiber, the brightness distribution line detectable on the brightness distribution image in correspondence to the reflected light received by the optical sensor device; and

detecting the orientation of the optical fiber according to a coordinate of the reference point on the brightness distribution image.

2. The method according to claim **1**, wherein the coordinate of the reference point is identified by comparing the brightness distribution line with a target distribution pattern representing a predetermined brightness distribution for the target orientation.

3. The method according to claim **2**, wherein the target distribution pattern represents a brightness distribution obtained when the collimated light is directed to the optical fiber maintained in the target orientation.

4. The method according to claim **1**, wherein a rotational angle of the optical fiber around an optical axis of the optical fiber is detected according to the coordinate of the reference point.

5. The method according to claim **1**, wherein an inclination angle of the optical fiber is detected relative to a plane, a direction of a normal of the plane being a propagation direction of the collimated light, according to the coordinate of the reference point.

6. The method according to claim **1**, wherein an angle of the optical fiber is detected relative to a certain direction on a plane, a direction of a normal of the plane being a propagation direction of the collimated light, according to an inclination angle of the brightness distribution line on the brightness distribution image.

7. An apparatus that detects an orientation of an optical fiber that is provided in an optical-transparent maintaining member including a flat surface as a part of a surface of the maintaining member, the apparatus comprising:

an optical system configured to direct collimated light to the optical fiber through the flat surface of the maintaining member and to receive reflected light of the collimated light; and

a computing processing system to:

calculate a brightness distribution image according to an output signal from the optical sensor device; and

identify a reference point on the brightness distribution image according to a position of a brightness distribution line, the brightness distribution line being formed on the brightness distribution image in correspondence to the reflected light received by the optical sensor device, and detect the orientation of the optical fiber according to a coordinate of the reference point on the brightness distribution image.

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